Pestic. Sci. 1997, **49**, 362–366

Assessing the Hazard to Granivorous Birds Feeding on Chemically Treated Seeds*

Michael L. Avery‡

USDA, National Wildlife Research Center, 2820 E. University Ave, Gainesville, FL 32641 USA

David L. Fischer

Bayer Corporation, Agriculture Division, 17745 South Metcalf, Stilwell, KS 66085 USA

& Thomas M. Primus

USDA, National Wildlife Research Center, Bldg 16, Federal Center, Denver, CO 80225 USA

(Received 12 February 1996; revised version received 1 July 1996; accepted 20 November 1996)

Abstract: Current methods for evaluating hazards to seed-eating birds are based on estimated exposure per unit area and assume that birds ingest all of the chemical on a treated seed. In an earlier study, however, it was determined that red-winged blackbirds removed only about 15% of an insecticidal treatment applied to individual rice seeds. Here, we extend those findings by examining the seed-handling behavior of four granivorous bird species exposed to millet, rice, sunflower and sorghum treated with imidacloprid. Mourning doves (*Zenaida macroura* L.) swallowed the seed whole. House finches (*Carpodacus mexicanus* Müller), red-winged blackbirds (*Agelaius phoeniceus* L.) and boat-tailed grackles (*Quiscalus major* Vieillot) discarded the seed hulls, however, and removed only 15–40% of the initial chemical treatment. Residues on seed hulls decreased as handling time increased. Sunflowers had the lowest residues because birds repeatedly handled the hull to remove bits of the oily kernel. These results suggest that avian hazard assessment methods should incorporate species-typical seed-handling behavior to assess more accurately birds' exposure to chemicals on different types of seed.

Key words: avian hazard, seed treatment, granivory, imidacloprid, handling time

1 INTRODUCTION

Birds foraging in and near agricultural fields are often exposed to seeds treated with a variety of insecticides and fungicides. Determining the hazard posed by such chemically treated seeds to granivorous birds is usually a required step in the Federal registration procedure.

The US Environmental Protection Agency (USEPA) Office of Pesticide Programs has several approaches for evaluating the avian risk from applications of pesticide-treated seeds. One is to determine the quantity of pesticide that will be applied and available to birds per square foot of treated area.[1,2] For the USEPA, the current regulatory level of concern is a quantity $\geq 1/2$ of the avian acute oral LD_{50}. Applications resulting in $\geqq 1/2$ of an LD_{50} dose per square foot are assumed to pose a high risk of bird mortality.[3] Applications resulting in $< 1/2$ of an LD_{50} dose per square foot are assumed to pose low risk.

A second approach that may be taken by USEPA is to compare the pesticide concentration of treated seeds to the avian dietary LC_{50}. If one makes the worst-case assumption that birds in the field will eat only treated seeds, it follows that a pesticide concentration $> 1/2$ of the avian LC_{50} (equivalent to roughly an LC_{10}) represents serious risk.

* Based on a paper presented at the 15th Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO, 30 October–3 November 1994.

‡ To whom correspondence should be addressed.

Pestic. Sci. 0031-613X/97/$17.50 © 1997 SCI. Printed in Great Britain

A third approach, somewhat similar to the preceding one, is to calculate the amount of toxicant ingested (mg kg^{-1}) per day, assuming that birds in the field eat only treated seeds. If this quantity exceeds half the oral LD_{50}, a high risk may be inferred.

Given certain basic facts, it is straightforward to calculate the number of seeds constituting an acute lethal dose. All that is needed is a measure of the compound's toxicity to the bird (LD_{50} or LC_{50}), the bird's mass, the seed mass, and the treatment rate on the seed. This basic procedure can apply to granules as well as to seeds.[2]

Such methods of hazard assessment usually include the assumption that the bird ingests all of the treatment on the seed. This is true for species that swallow the entire seed. Beyond that, however, there is a gradient of exposure, based on seed-handling behavior, among seed-eaters that remove the outer hull prior to ingestion. These birds will receive less than the entire chemical treatment. How much less is probably related to how long the seeds are handled. Presumably, exposure will increase with handling time. In turn, handling time is likely to be directly affected by the relationship between bill morphology and seed size.[4]

The concept that all of the chemical applied to a seed may not be ingested is not new. For example, Urban and Cook[2] [p. 85] mention it as a consideration in avian risk assessments: 'Certain seeds will not be eaten *in toto*. Instead, only the inside unexposed portions will be ingested, leaving the shell, hull or pod.' Despite this recognition, however, empirical data relevant to this potentially important qualification are scarce.

In a previous study, when male red-winged blackbirds (*Agelaius phoeniceus* L.) fed on imidacloprid-treated rice seeds, approximately 85% of the original treatment remained on the discarded seed hulls.[5] Based on these earlier findings, we felt it important to expand this inquiry to other species of birds and other types of seed. Here, we document the seed-handling behavior of red-winged blackbirds, house finches (*Carpodacus mexicanus* Müller), mourning doves (*Zenaida macroura* L.), and boat-tailed grackles (*Quiscalus major* Vieillot) feeding on seeds of rice, sunflower, millet and sorghum. We presented birds with seeds treated with imidacloprid, a systemic insecticide,[6] and then we recovered the seed hulls to determine the proportion of the original treatment remaining and to estimate species- and seed-specific levels of exposure to the chemical treatment. We illustrate how consideration of seed-handling behavior could affect avian hazard assessment of chemical seed treatments.

2 METHODS

Seeds were treated with imidacloprid ('Gaucho'®) 480 FS, Gustafson, Inc., Dallas, TX) at the Gustafson Research and Development Center, McKinney, TX. Chemical analyses were performed at ABC Laboratories, Columbia, MO following previously published methods.[7]

We conducted feeding trials at the Florida Field Station of the US Department of Agriculture's National Wildlife Research Center in Gainesville. We tested birds individually in 45 × 45 × 45-cm cages. Birds were maintained on a mixture of commercial gamebird feed (F-R-M® Flint River Mills, Bainbridge, GA) and white millet, rice (cv. Lemont), sorghum (cv. DK56) and sunflower (cv. Pioneer 6440). Each morning at 0730, we removed the maintenance food and 1 h later provided 15 g of test seed in a clear plastic cup. Generally, we offered one type of untreated seed one day, followed by imidacloprid-treated seed the next. Pans below each cage collected spillage. After 2 h, we collected the food cups and pans, weighed the contents to determine consumption and separated the hulls. We placed hulls in labeled plastic bags and froze them for residue analysis.

During each trial, we videotaped a bird to quantify its seed-handling behavior. The bird was not selected randomly but was chosen on the basis of the consumption of untreated seed to ensure that we taped actively feeding birds. Then, the video tapes were played back in slow motion and the handling of treated seeds quantified. We defined handling time as the interval from when the bird picked up the seed to the time the seed hull fell from the bird's bill.[4] We also recorded the number of seeds eaten during the bird's initial feeding bout. We analyzed consumption of untreated and treated seeds with paired t-tests.

We randomly selected 10 sets of 25 seeds of each seed type and determined the mass of each set. Also, hulls were separated from millet, rice and sunflower seeds to determine the portion of the seed that was hull. We divided those proportions into the seed hull residues to enable us to compare residues on hulls with those on whole seeds.[5] We examined the relationship between seed-handling time and chemical residue with regression analysis.

3 RESULTS

3.1 Seed consumption

Imidacloprid reduced seed consumption across the four bird species (Table 1). The trend of reduced consumption from untreated seeds to treated seeds was apparent even in the few instances that lacked statistical significance.

3.2 Seed handling

Mourning doves swallowed seed whole. They ate rice and sunflower sparingly, but swallowed millet and

TABLE 1
Seed Consumption with and without Imidacloprid, by Four Species of Birds in Two-Hour, One-Cup Trials

Bird species	*N*	*Seed*	*Seed consumption (g per bird) (±SE)* Untreated	Treated	P^a
House finch	10	millet	0·75 (±0·08)	0·33 (±0·04)	0·0013
	10	rice	0·17 (±0·07)	0·14 (±0·06)	0·63
	9	sorghum	0·18 (±0·04)	0·04 (±0·01)	0·013
Red-winged	8	millet	2·26 (±0·13)	0·65 (±0·11)	<0·001
blackbird	7	sorghum	0·84 (±0·26)	0·29 (±0·08)	0·033
Boat-tailed	8	millet	1·97 (±0·51)	0·33 (±0·07)	0·009
grackle	6	rice	2·01 (±1·04)	0·22 (±0·14)	0·15
Mourning	9	millet	1·46 (±0·40)	0·47 (±0·16)	0·0062
dove	9	sorghum	0·37 (±0·22)	0·06 (±0·01)	0·21
	9	sunflower	0·34 (±0·06)	0·06 (±0·02)	0·003

[a] Result of paired t-tests.

sorghum at rates of 98 seeds min^{-1} and 21 seeds min^{-1}, respectively.

We recovered no hulls from millet eaten by boat-tailed grackles. Unlike doves, the grackles handled the millet seeds in their beak, but ate the entire seed (11 seeds min^{-1}). This species did, however, remove seed hulls of rice (3·0 s per seed) and sunflower (6·1 s per seed) prior to ingestion. Sorghum was rarely eaten.

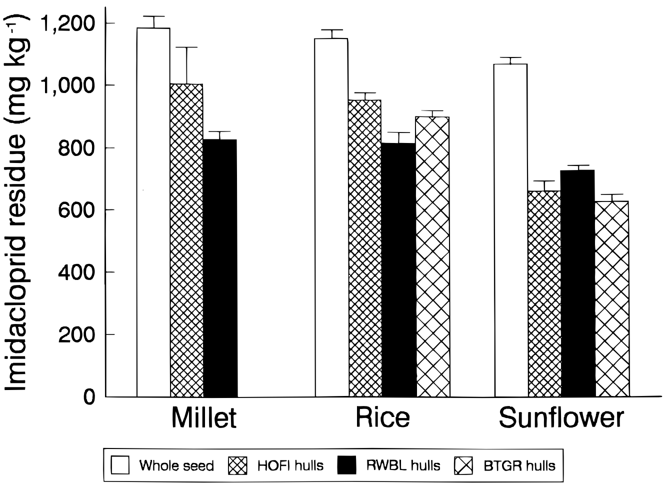

Fig. 1. Imidacloprid residue on whole seeds and on hulls of seeds eaten by house finches, red-winged blackbirds and boat-tailed grackles. Hull residues were calculated by dividing the measured residues on the hulls by the proportion of seed mass represented by hulls. Capped bars denote 1 SE.

Red-winged blackbirds removed hulls from millet, rice and sunflower. Mean handling times (s per seed) were 1·4 (millet), 1·8 (sunflower) and 3·9 (rice). The outer coating of sorghum is not readily separable from the rest of the seed, and blackbirds that ate sorghum crushed the seeds and then picked at the pieces.

House finches removed the hulls from all seeds except sorghum which they crushed as the redwings did. Mean handling times (s per seed) were 1·6 (millet), 3·4 (rice) and 5·7 (sunflower). In eating the sunflower seeds, the house finches, like the blackbirds and grackles, repeatedly handled the shell fragments after the seed was initially cracked open. Frequently, it appeared that parts of the oily sunflower kernel adhered to the hull fragments and the birds maneuvered the fragments with their beak to remove the bits of germ before selecting a new seed. Birds did not repeatedly handle hull fragments of rice or millet.

3.3 Residues

Imidacloprid concentration on whole seeds ranged from 1055 mg kg^{-1} on sorghum to 1185 mg kg^{-1} on millet (Table 2). Residues on hulls from seeds eaten by birds

TABLE 2
Seed Mass and Imidacloprid Treatment Levels

Seed type	*Mass of 25 seeds (g) (±SE)*	*Hull mass/ total mass (±SE)*	*Imidacloprid on whole seed (mg kg^{-1}) (±SE)*
Millet	0·144 (±0·002)	0·23 (±0·01)	1185 (±35)
Rice	0·681 (±0·005)	0·16 (±0·01)	1150 (±20)
Sunflower	1·635 (±0·017)	0·20 (±0·01)	1070 (±10)
Sorghum	0·773 (±0·013)	—	1055 (±25)

ranged from 3155 mg kg^{-1} on sunflower hulls handled by grackles to 5305 mg kg^{-1} on rice handled by house finches. When hull residues were adjusted for the proportion of hull mass in total seed mass, the amount of imidacloprid removed ranged from 15% for finches eating millet to 41% for grackles eating sunflower (Fig. 1). Overall, imidacloprid residues decreased linearly with increased handling time ($F = 7{\cdot}47$; 1,6 df; $P = 0{\cdot}034$, SD about regression line $= 0{\cdot}068$)

4 DISCUSSION

Many factors contribute to a bird's exposure to chemicals on a seed. In this study we documented the effects of a single factor, seed-handling behavior, and show that the species of bird and type of seed can affect the estimate of avian hazard. Furthermore, we have extended previous findings[5,8] by showing that avian seed consumption is reduced by imidacloprid treatment.

A hypothetical example will illustrate how our results could affect avian hazard evaluations. Suppose a compound has an LD_{50} of 40 mg kg^{-1} for a 50-g bird, which is equivalent to 2 mg per bird. Furthermore, assume that the rate of treatment on a 25-mg seed is 0·2% (w/w), or 2000 mg kg^{-1}. The LD_{50} dose would be obtained by completely ingesting 40 25-mg treated seeds. At a typical feeding rate of four or five seeds per min[9] a red-winged blackbird, which weighs approximately 50 g, could easily consume 40 rice seeds in an 8 to 10-min feeding bout. Furthermore, if this seed is applied at a rate of 100 lb acre^{-1}, which is typical for rice production, then there will be approximately 40 seeds per square foot, or 1 LD_{50} per square foot. This will result in a finding of high avian hazard.[3]

From our study, however, we determined that, except for doves, birds feeding on treated seeds ingest only a fraction of the total treatment. Thus, if a bird, such as a red-winged blackbird, removes 30% of the chemical, then the acute oral LD_{50} changes from 40 seeds to 133 seeds. To obtain such a dose, a bird would have to eat five seeds min^{-1} for 27 min. On an area basis, a square foot would now contain 30% of an acute oral LD_{50} which puts the hazard potential into the low category, considerably altering the risk estimate.

A mourning dove weighs about 100 g, and in this example would require 4 mg for an acute oral LD_{50}, assuming a constant proportional relationship between body mass and toxicity. A dove would obtain this dose by eating 80 25-mg seeds. Given that we recorded doves feeding on sorghum, a 30-mg seed, at rates of approximately 30 min^{-1}, a potentially lethal dose could be obtained quickly. Thus, the sorghum–dove combination has high potential risk.

If a similar-sized seed such as rice (27 mg per seed) is considered, however, the risk is negligible because doves do not tend to eat rice (in two 2-h tests with untreated rice, only three of nine doves ate any). Furthermore, doves do not favor muddy rice field sites where this seed would be encountered in the field.[10,11]

Hazard assessment should be specific to a particular bird species feeding on a given type of seed. As we have shown, handling times and chemical residues vary across seed types within species and across species eating the same type of seed. We examined 16 possible granivorous bird–seed type combinations. Because of the birds' seed-handling behavior, the aversiveness of the imidacloprid treatment and the birds' seed preferences, only the dove–sorghum and perhaps the dove–sunflower combinations should pose high risks.

Generally, handling time increases (and hence so does exposure) with increased seed size (Fig. 2). In addition to size, however, the physical nature of the seed is also important. In our study, finches, blackbirds and grackles manipulated sunflower seed fragments repeatedly in order to extract the bits of oily seed kernel adhering to the shell. Millet and rice hulls separated cleanly and so were not picked up again. Consequently, residues were lowest on sunflower hulls.

Once a bird picks up a seed, reducing avian hazard means decreasing the time the seed is handled or making the chemical less available to the birds. Our findings suggest that the inherent seed-handling behavior of most granivorous birds results in their not being exposed to 60–85% of the chemical that is on the seed. Handling could be further reduced by adding a contact repellent or irritant to the seed treatment formulation.[12] Other formulation improvements that encapsulate the potential toxin would also reduce potential hazard.

For birds such as doves that swallow seeds without removing the hull, other mitigative approaches may be required. These could include altering the seed's appearance so that it is not picked up, adding aversive tasting chemicals to the coating, or providing highly preferred

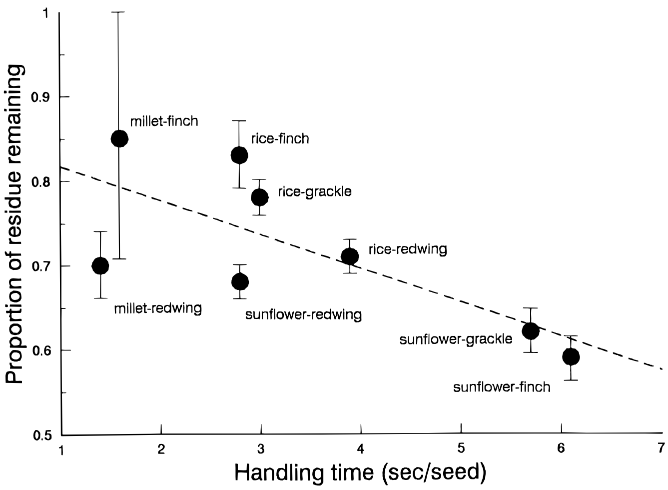

Fig. 2. Handling times and proportion of initial imidacloprid left on hulls of seeds eaten by house finches, red-winged blackbirds and boat-tailed grackles. The regression line is described by the equation: Residue $= 0{\cdot}86 - 0{\cdot}04 \times$ handling time. Capped bars denote ± 1 SE for each residue determination.

alternative food. Birds will avoid pesticide-treated food if they have alternatives.[13,14] Recent experiments (Avery, M. L., unpublished) indicate that calcium carbonate applied to sorghum seed can cause mourning doves to switch from eating sorghum to eating millet in 24-h pen trials. Techniques such as this could substantially reduce birds' exposure to chemicals on seeds.

ACKNOWLEDGEMENTS

S. Shen and P. McFadden provided the test material; W. Williams supervised residue analyses; D. Decker and C. Laukert assisted in collecting and recording data; K. Roca cared for the birds; and L. Whitehead typed the manuscript.

REFERENCES

1. DeWitt, J. B., Methodology for determining toxicity of pesticides to wild vertebrates. *J. Appl. Ecol.*, **3** (1966) 275–8.
2. Urban, D. J. & Cook, N. J., *Standard evaluation procedure: ecological risk assessment*. US Environmental Protection Agency, Office of Pesticide Programs. EPA-540/9-85-001, Washington, DC, 1986.
3. Fisher, L. J., *Decisions on the ecological, fate and effects task force*. Memorandum from Assistant Administrator, US Environmental Protection Agency to D. Campt, Director, Office of Pesticide Programs. Washington, DC, 29 October 1992.
4. Pulliam, H. R., Ecological community theory and the coexistence of sparrows. *Ecology*, **64** (1983) 45–52.
5. Avery, M. L., Decker, D. G. & Fischer, D. L., Cage and flight pen evaluation of avian repellency and hazard associated with imidacloprid-treated rice seed. *Crop Protect.*, **13** (1994) 535–40.
6. Mullins, J. W., Imidacloprid: a new nitroguanidine insecticide. In *Pest Control with Enhanced Environmental Safety*, ed. S. O. Duke, J. J. Menn and J. R. Plimmer. Amer. Chem. Soc. Symposium Ser. 524, Washington, DC, 1993, pp. 183–98.
7. Ishii, Y., Kobori, I., Araki, Y., Kurogochi, S., Iwaya, K. & Kagabu, S., HPLC determination of the new insecticide imidacloprid and its behavior in rice and cucumber. *J. Agric. Food Chem.*, **42** (1994) 2917–21.
8. Avery, M. L., Decker, D. G., Fischer, D. L. & Stafford, T. R., Responses of captive blackbirds to a new insecticidal seed treatment. *J. Wildl. Manage.*, **57** (1993) 652–6.
9. Avery, M. L., Decker, D. G. & Way, M. O., Field tests of a copper-based fungicide as a bird repellent seed treatment. *Proc Vertebr. Pest Conf.*, **16** (1994) 250–4.
10. Cummings, J. L., Glahn, J. F., Wilson, E. A. Davis, J. E., Jr, Bergman, D. L. & Harper, G. A., *Efficacy and nontarget hazards of DRC-1339 treated rice baits used to reduce roosting populations of depredating blackbirds in Louisiana. Denver Wildl. Res. Cent. Bird Section Res. Rep. 481*, Denver, Colorado, 1992.
11. Glahn, J. R. & Wilson, E. A., Effectiveness of DRC-1339 baiting for reducing blackbird damage to sprouting rice. *Proc. East. Wildl. Damage Control Conf.*, **5** (1992) 117–23.
12. Mason, J. R., Clark, L. & Miller, T. P., Evaluation of a pelleted bait containing methyl anthranilate as a bird repellent. *Pestic. Sci.*, **39** (1993) 299–304.
13. Hill, E. F., Avoidance of lethal dietary concentrations of insecticide by house sparrows. *J. Wildl. Manage.*, **36** (1972) 635–9.
14. Bennett, R. S., Jr & Prince, H. H., Influence of agricultural pesticides on food preference and consumption by ring-necked pheasants. *J. Wildl. Manage.*, **45** (1981) 74–82.